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The Marginal External Cost of Car Use[1] - with an Application to Belgium -

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I. INTRODUCTION

Road space is a valuable and increasingly scarce resource. Therefore it is argued by economists that its use should be rationed by price. In order to induce road users to make the correct decisions about whether and by which mode to make a particular journey, they should be charged the marginal social cost of using the road network. Due to the existence of negative externalities, this marginal social cost may differ from the marginal private cost paid by the road users. Marginal external costs are costs caused by the additional use of the road network which are not borne by the additional road user himself but by others: the other road users or society in general.

The aim of this paper is to develop a quantitative measure of the marginal external costs associated with passenger car use in Belgium. It concentrates on three main external cost categories: environmental costs, congestion costs and accident costs. Several elements for the monetary valuation of the marginal external costs of the different transport modes for Belgium were discussed by Blauwens (1991) and in the Mobilis report (Febiac (1992)). However, except for the marginal congestion costs, no concrete values were derived. Concrete monetary values of the marginal external costs of road transport in the UK were estimated by Newbery ((1987), (1988),

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(1990)). He did not quantify the marginal environmental costs, but expected them to be only a small proportion of total marginal external costs. This is one of the aspects which will be investigated in detail in this paper. An alternative to Newbery's derivation of marginal accident externalities is found in Jones-Lee (1990).

The structure of this paper is as follows. In section II a simple theoretical model is presented which illustrates how the total costs per km associated with a given traffic flow change as a result of an additional passenger car km. Section III then discusses the monetary valuation of the external costs caused by this additional passenger car km for the particular case of Belgium. We conclude by some warnings about the potential use of the results in policy formulation.

II. A SIMPLE THEORETICAL MODEL

Consider the following initial situation. Traffic flow consists of q passenger car equivalent units (PCU) per hour. In order to keep the analysis simple, the model assumes there are only two types of vehicles: passenger cars (PC) and trucks (T). The model can readily be extended to include other vehicle types. A truck is assumed to correspond with y PCU. This reflects the difference in congestive effect between trucks and passenger cars. The proportion of passenger cars in the traffic flow is given by x. (1-x) then represents the proportion of trucks.

The total number of trucks is given by

$$T = \frac{(1-x)\ q}{y} \tag{1}$$

Total costs per km corresponding with traffic flow q are given by the sum of four components: total private user costs (C), total environmental costs (E), total accident costs (A) and total road maintenance and infrastructure costs (I).

In the further theoretical discussion it is assumed that all cars and their occupants are identical. The same assumption is made for trucks. Then private user costs per km for a traffic flow q are given by

$$C = PC\ [\ t_{PC}(s) + u_{PC}(s,r)\ ] + T\ [t_T(s) + u_T(s,r)] \tag{2}$$

where

$t_i(s)$: time costs per km of vehicle type i (i=PC,T)
$u_i(s,r)$: vehicle operating costs per km of vehicle type i (excl. of taxes)

It is assumed that both t_i and u_i depend on speed s (expressed in km/h). Speed is determined by the so-called speed-flow relationship

$$s = s(q) \tag{3}$$

Moreover, u_i is assumed to depend on r, the state of the road which is defined as a function of the number of trucks and of a number of other factors f.

$$r = r\ (T, f\ ) \tag{4}$$

The environmental costs per km are defined as

$$E = PC\ .\ p_{PC}(s)\ +\ T\ .\ p_T(s) \tag{5}$$

where

pi(s): pollution costs per km of vehicle type i

Accident costs are:

$$A = PC\ z \sum_j a_j\,(s, q, x, h, N)\, v_j + T \sum_j d_j\,(s, q, x, h, N)\, e_j + N \sum_j b_j\,(s, q, x, h, N)\, w_j \tag{6}$$

where:

a_j: risk that an accident of type j happens to a passenger car (j = fatal accident, serious injury, light injury, material damage); a_j depends on the speed at which the traffic flow moves (s), on traffic flow (q), on traffic composition (x), on the number of pedestrians and cyclists (N) and on a number of other factors (h)
d_j: risk that an accident of type j happens to a truck

b_j: risk that an accident of type j happens to a pedestrian or a cyclist

v_j: monetary valuation of an accident of type j happening to an occupant of a passenger car

e_j: monetary valuation of an accident of type j happening to a truck

w_j: monetary valuation of an accident of type j happening to a pedestrian or a cyclist

z : average occupancy rate of a passenger car

Road infrastructure and maintenance costs are defined as

$$I = m(r(T, f)) + o(l) \tag{7}$$

where :

m(r): road maintenance cost per km, a function of the state of the road

o(l): road operating costs per km which are assumed to be independent of traffic flow and to depend on a number of other factors (l)

So, it is assumed that road maintenance and operating costs are independent of the number of passenger cars. This assumption is based on Newbery (1990).

If an additional passenger car drives a km on the road, total costs will change as follows (using δq / δPC = 1)

$$\begin{aligned}\frac{\delta TC}{\delta PC} = {} & t_{PC}(s) + u_{PC}(s) + \left[PC\left(\frac{\delta t_{PC}(s)}{\delta s} + \frac{\delta u_{PC}(s)}{\delta s} \right) + T\left(\frac{\delta t_T(s)}{\delta s} + \frac{\delta u_T(s)}{\delta s} \right) \right] \frac{\delta s}{\delta q} \\ & + p_{PC}(s) + \left(PC \frac{\delta p_{PC}(s)}{\delta s} + T \frac{\delta p_T(s)}{\delta s} \right) \frac{\delta s}{\delta q} + z \sum_j a_j v_j + PC\, z \sum_j \frac{da_j}{dPC} v_j \\ & + T \sum_j \frac{dd_j}{dPC} e_j + N \sum_j \frac{db_j}{dPC} w_j \end{aligned} \tag{8}$$

where

$$\frac{da_j}{dPC} = \frac{\delta a_j}{\delta s} \frac{\delta s}{\delta q} \frac{\delta q}{\delta PC} + \frac{\delta a_j}{\delta q} \frac{\delta q}{\delta PC} + \frac{\delta a_j}{\delta x} \frac{\delta x}{\delta PC} \tag{9}$$

Similar expressions hold for db_j /dPC and dd_j /dPC. From equation (9) it is clear that a change in the number of passenger cars may influence accident risks in several ways: through its effect on the speed at which the traffic flow moves, through its effect on the number of passenger car units and through its effect on traffic composition.

Equation (8) shows that if an additional passenger car drives one km, this has several impacts on total costs. These impacts and their description are summarized in Table 1. For each of the effects the table also describes who bears the costs. Not all marginal cost categories presented in Table 1 are external. Category (a) belongs to the private costs of the driver and passengers of the additional car and will therefore not be discussed any further in this paper.

Part of marginal accident costs (e), (f) and (g) are covered by the insurance contract of the driver of the additional car and thus cannot be considered as an external cost. This aspect will be discussed in a more detailed way in a later section of this paper. The other marginal cost categories can be considered as external. Together with the external part of the marginal accident costs they constitute the total marginal external cost associated with an additional car-km. Part III discusses the monetary valuation of these different categories of marginal external costs for the case of Belgium.

III. THE MONETARY VALUATION OF THE EXTERNAL COSTS OF AN ADDITIONAL PASSENGER CAR KM

The external costs of an additional passenger car km are calculated for three different road types and different levels of congestion. The road types considered are: urban roads, highways and other roads. For urban and "other" roads traffic is assumed to be composed of three vehicle types: cars, buses and trucks. In the case of highways only two vehicle types are considered: passenger cars and trucks. Table 2 summarizes for each road type the different levels of congestion considered and the basic assumptions on traffic composition.

A. *Marginal congestion costs*

In road transport marginal congestion costs take place whenever an additional vehicle on the road slows down the others. As was shown in the theoretical model, slower speed has several effects. First of all, it influences time and operating costs of the other road users.

Secondly, it also has an impact on environmental costs and accident risks. This section will only cover the first two effects. The monetary valuation of the latter two effects will be discussed in sections III.B and III.C.

For the calculation of the marginal congestion costs it is assumed that congestion does not influence the demand of the other road users. The marginal congestion costs we discuss here are thus short-

TABLE 1

Total marginal costs associated with an additional car km

	Impact	Description	Costs borne by
a	$t_{PC}(s) + u_{PC}(s)$	Private user costs (time + vehicle operating costs (excl. of taxation))	Occupants of the additional car
b	$\frac{\delta s}{\delta q} \{ PC [\frac{\delta t_{PC}(s)}{\delta s} + \frac{\delta u_{PC}(s)}{\delta s}] + T [\frac{\delta t_T(s)}{\delta s} + \frac{\delta u_T(s)}{\delta s}] \}$	Marginal short-run congestion costs	Trucks and occupants of other cars
c	$p_{PC}(s)$	Marginal direct environmental costs	Society
d	$\frac{\delta s}{\delta q} \{ PC \frac{\delta p_{PC}(s)}{\delta s} + T \frac{\delta p_T(s)}{\delta s} \}$	Marginal indirect environmental costs	Society
e	$\sum_j a_j v_j$	Marginal accident costs associated with the risk of death or injury to the occupants of the additional car	Occupants of the additional car Their relatives and friends Society

TABLE 1 (continued)

Total marginal costs associated with an additional car km

	Impact	Description	Costs borne by
f	$PC \sum_j \frac{da_j}{dPC} v_j + T \sum_j \frac{dd_j}{dPC} e_j$	Marginal accident costs associated with the increased risk of death or injury to the occupants of other cars and to trucks	Occupants of the additional car Trucks and occupants of other cars Society
g	$n \sum_j \frac{db_j}{dPC} w_j$	Marginal accident costs associated with the increased risk of death or injury to pedestrians and cyclists	Pedestrians and cyclists Society

TABLE 2

Cases considered in the empirical exercise for Belgium

	ROAD TYPE		
	URBAN ROAD	HIGHWAY	OTHER ROAD
Level of congestion	Off-peak Peak	No congestion Light congestion Medium congestion Heavy congestion	No congestion Light congestion Heavy congestion
BASIC HYPOTHESES			
Traffic composition			
% of cars	95	75	80
% of buses	4	0	5
% of trucks	1	25	15
Passenger cars: share of different fuel types:[2]			
% gasoline	74.12	74.12	74.12
% diesel	24.65	24.65	24.65
% LPG	1.23	1.23	1.23

run in nature[3]. They consist of the costs imposed on other traffic assuming no response from other road users.

Central in the calculation of the marginal congestion costs is the speed-flow relationship which describes how average speed (s) is influenced by traffic flow (q). Traffic flow is measured in passenger car units (PCU) per hour. PCU are used instead of the number of vehicles to reflect the difference in congestive effect of the vehicle types considered. A bus or a truck are assumed to correspond with 2 PCU.

For our analysis we assume that the following speed-flow relationships hold:

ROAD TYPE	SPEED-FLOW RELATIONSHIP	
Urban road (2x1 lanes)	s = 45.725-0.035*q (q: PCU/lane/h)	
Highway (2x2 lanes)	s = 115 s = 115-0.00274*(q-1500) s = 115-0.00274*2100-0.03606*(q-3600) (q: PCU/direction/h)	q <= 115 1500<q<=3600 q>3600
Other road (2x1 lanes)	s = 74.5 s = 74.5-0.00975*(q-300) (q: PCU/lane/h)	q<=300 q>300

Blauwens (1991) points out that one can only use speed-flow relationships to calculate marginal external congestion costs if traffic is still moving and has not come to a complete standstill. According to him, the latter case requires a different method based on the method used in the case of waiting lines at airports, sluices or ferry services. This method seems to be appropriate when looking at congestion problems at different points in the network separately. If one looks at the congestion problem in a more integrated way, then the speed-flow relationship should reflect in some way the relationship between average speed from origin to destination of a trip and the relevant traffic flow (Newbery (1988)). In that case one does not have to treat stationary traffic in a separate way: its effect on speed and time costs is already incorporated through the average speed. It is the latter approach which is chosen in this paper.

1. Time costs

The speed-flow relationships allow us to calculate the time loss suffered by the other road users if an additional passenger car joins the traffic flow. In order to express this time loss in monetary terms, we base ourselves on recent value of time (VOT) studies for the Netherlands. Such studies exist both for passenger and freight transport.

For passenger transport, a willingness-to-pay (WTP) study carried out for the Netherlands by the Hague Consulting Group (1990) provides empirical evidence about money valuations of travel time savings or losses by travellers using private cars and public transport. The methodology used and the results obtained are discussed extensively by Hague Consulting Group (1990) and Bradley and Gunn (1991). Table 3 summarizes the representative time-weighted average VOT which were obtained for car drivers and users of public transport. We will use these results as a first approximation in our analysis for Belgium. The values refer to in-vehicle time. A distinction is made between three journey purposes: business, commuting and other motives. The results were derived on the basis of stated preference information: travellers were interviewed to elicit their preferences concerning possible but hypothetical travel options which differed in terms of travel time and costs. For the business motive, the VOT derived from the stated preference study only reflects the value to the worker himself and not to the employer. Therefore the stated preference figure is increased with the employer's value of business travel (Bradley and Gunn (1991)). The total value thus obtained is presented in Table 3.

TABLE 3

Representative time-weighted average VOT for car drivers (Bradley (1990))

JOURNEY PURPOSE	VALUE OF TIME (BF 1989/hour)
CAR	
Commuting	218.35
Business	717.67
Other	172.74
BUS	
Commuting	182.94
Business	717.20
Other	108.16

The results of HCG must be combined with data on the importance of the three trip motives. It can be expected that their importance will not be the same for the two transport modes, the three road types and the different levels of congestion considered. Data on the percentage of total vehicle-km devoted to commuting, business and other purposes as given by De Borger (1987) do not entirely serve our purpose. For city traffic we have based ourselves on data for Brussels provided by Stratec (1992). For traffic on highways and other roads we do not dispose at this moment of similar information. As a first approximation we therefore formulate hypotheses on the importance of the trip motives on these two road types. Of course this approach needs to be changed when better data become available.

The calculation of the marginal external time costs also requires data on the average vehicle occupancy rate. For passenger cars it is assumed that this rate is 1.2 in the case of commuting and business travel. For other journey purposes an average vehicle occupancy rate of 1.8 is assumed. These values are close to the ones put forward by the British Department of Transport in its COBA-9 manual (Great Britain, Department of Transport (1987)). For buses average vehicle occupancy rates of 37 and 15 are assumed for respectively peak and off-peak period. The former is based on Small (1983).

The VOT in freight transport can be estimated by means of several methods. A brief overview is given in De Jong et al. (1992). We will limit ourselves here to the discussion of two VOT studies for freight transport. Blauwens and Van de Voorde (1988) estimate the VOT in freight transport by means of an aggregate revealed preference model. They consider the particular case of competition between road haulage and inland navigation. The modal choice is a function of the difference in time between the two transport modes as well of the difference in costs. Estimating an econometric function which describes this relationship yields that in the commodity transportation sector the value of one hour is equal to 0.0000848 times the value of the goods transported. The VOT is thus found to be proportional to the value of the goods.

In De Jong et al. (1992) short and medium term VOT in freight transport are estimated by means of the contextual stated preference method. The study concerns all freight transport in the Netherlands using the modes road, rail and inland waterways. For road transport different good categories were considered. Respondents were asked to choose between different alternatives for a typical transport they were involved in. The choice alternatives were within-mode and differed with respect to five characteristics: transport costs, travel time, travel time reliability, probability of damage and frequency of shipment. The authors estimated the effect of a percentage change in each of these characteristics on the respondent's utility. By applying the ratio between the time and the cost coefficient to the hourly transport cost, estimates for the VOT were obtained. The results are presented in Table 4.

TABLE 4

VOT in freight transport (De Jong et al. (1992))

	Hourly transport cost (BF 1989)	Trade-off ratio	Freight VOT (BF 1989)
Road A	1094	1.028	1125
Road B	1154	1.076	1242
Road C	1133	0.934	1058
Road D	1159	0.826	957
Road: average	1130	0.936	1058

Goods categories:
A: low value raw materials and semi-finished goods
B: high value raw materials and semi-finished goods
C: finished goods with loss of value
D: finished goods without loss of value

It is found that the VOT for transporting raw materials and semi-finished goods is higher than the value for finished products. The authors explain this by the fact that raw materials and semi-finished goods need further processing. Delays during transport may lead to delays in the production process, with all subsequent costs. The VOT is higher for finished products with potential loss of value than for finished products without loss of value.

In the empirical exercise, we use the results of De Jong et al. Since we do not yet dispose of data concerning the importance of the four different goods categories, we use the average value for goods transport by road.

2. Operating costs

Slowing down other vehicles also has an effect on their operating costs. In this paper we will approximate this effect by the change in fuel costs. In order to do so we need information on the relationship between fuel consumption and speed. For gasoline passenger cars detailed information on this relationship is found in Zierock et al. (1989). However we do not dispose of such detailed data for passenger cars running on diesel or LPG or for trucks. The effect on their operating costs is therefore not yet considered in this analysis.

3. Results

Table 5 presents the total short-run marginal congestion costs as they are calculated based on the assumptions put forward in this section. It can be observed that they consist mainly of marginal external time costs. For some traffic conditions, the marginal external fuel costs are negative, reflecting the fact that in those cases a decrease in speed is accompanied by a decrease in fuel consumption. The importance of the marginal external fuel costs, which act as a proxy for the marginal external vehicle operating costs, is only minor. It should be noted however that the estimation procedure for these costs only takes into account the effect on the fuel costs of gasoline cars. Nevertheless, it can be expected that the importance of the marginal fuel costs will remain small even if the effect on the fuel costs of other vehicle types is incorporated. Furthermore, it is expected that the inclusion of other non-fuel vehicle operating costs will not change this conclusion.

The level of the marginal external time costs is shown to vary widely according to the road type and the level of congestion. It ranges from BF 0 in the cases without congestion to approximately BF 74 in the case of heavy congestion on highways. In peak circumstances on urban and "other" roads a value of resp. BF 12.8 and BF 4.40 is obtained. The results given in Table 5 are only valid under the assumptions put forward in the previous paragraphs. They depend heavily on the assumed traffic composition and on the importance of the different journey purposes for passenger cars. For instance, if one assumes in the case of heavy congestion on highways that 80% of passenger cars are used for "other" purposes and only 10% for business purposes and commuting each, then the marginal external time costs decrease from approximately BF 74 to around BF 66.

TABLE 5

The marginal external congestion costs: monetary valuation

	URBAN		HIGHWAY				OTHER		
	Off peak	Peak	No congestion	Light congestion	Medium congestion	Heavy congestion	No congestion	Light congestion	Heavy congestion
Initial traffic flow	210	472.5	1375	3125	4500	5625	180	480	2040
New traffic flow	211	473.5	1376	3126	4501	5626	181	481	2041
Initial speed (km/h)	38.3750	29.1875	115	110.5475	76.7920	36.2245	74.5	72.7450	57.5350
New speed (km/h)	38.3400	29.1525	115	110.5448	76.7559	36.1884	74.5	72.7353	57.5253
Journey purpose passenger cars:									
% commuting	27.0%	51.0%	20.0%	25.0%	25.0%	60.0%	20.0%	20.0%	40.0%
% business	17.0%	17.5%	20.0%	30.0%	30.0%	30.0%	20.0%	20.0%	20.0%
% other	56.0%	31.5%	60.0%	45.0%	45.0%	10.0%	60.0%	60.0%	40.0%
Journey purpose bus passengers									
% commuting	23.0%	47.0%	-	-	-	-	20.0%	20.0%	60.0%
% business	15.0%	10.0%	-	-	-	-	5.0%	5.0%	10.0%
% other	62.0%	43.0%	-	-	-	-	75.0%	75.0%	30.0%
MARGINAL EXTERNAL TIME COSTS									
Time loss per vehicle (min)	0.001427	0.002468	0	0.000013	0.000367	0.00165	0	0.000111	0.000177
Total monetary value of time loss (BF 1989/Car-km)									
Cars	1.7695	6.7223	0	0.1951	7.6646	41.4597	0	0.2426	1.6086
Buses	0.6183	5.5927	-	-	-	-	0	0.2092	1.9817
Trucks	0.0503	0.1958	0	0.1482	5.8240	32.7332	0	0.1169	0.7946
Total	2.4381	12.5108	0	0.3433	13.4886	74.1929	0	0.5688	4.3850
MARGINAL EXTERNAL FUEL COSTS (BF 1989/Car-km)(only for gasoline passenger cars)	0.0719	0.2567	0	-0.0303	-0.1402	1.4497	0	-0.0029	0.0198
TOTAL MARGINAL EXTERNAL CONGESTION COSTS (BF 1989 / Car-km)	2.5100	12.7675	0	0.3130	13.3484	75.6426	0	0.5659	4.4048

B. *Marginal external environmental costs*

The marginal environmental costs caused by an additional car-km are diverse. In this section we will concentrate on two main categories of environmental costs: air pollution and noise[4].

1. The marginal external air pollution costs associated with car use

In the empirical exercise we will limit ourselves to the air pollution problems associated with NO_x, SO_2, HC and CO_2. Due to a lack of information, lead, CO and particulates could not yet be incorporated. In order to estimate the marginal social air pollution costs associated with an additional car km, two major steps have to be undertaken: the determination of the effect on emissions of an additional car-km and the monetary valuation of this change in emissions.

a. The effect on emissions of an additional car-km

The first step consists of determining how the emission of the different air pollutants changes as a result of the additional car-km. We will limit ourselves to the emission of SO_2, CO_2, HC and NO_x. As was shown in the theoretical model of section II, we have to make a distinction between the direct and the indirect effect on emissions. First of all, the additional car-km driven at a given speed will emit itself a volume of air pollutants. Secondly, by influencing the speed of the other road users, it will have an impact on the volume of their emissions.

In order to derive both the direct and the indirect effect on emissions, information is needed on the volume of the air pollutants emitted by individual vehicles. This information is found in a study by the Corinair working group on emission factors for road traffic in which a set of emission factors were proposed to be used for the 1985 Corinair emission inventory (Zierock et al. (1989)). It presents a.o. emission factors for NO_x and HC (incl. methane). A distinction is made between three types of emissions. The first type are "hot emissions" which are emitted by vehicles after they have warmed up to their normal operating temperature. The second type are "cold emissions" which are emitted while the vehicles are warming up. The third type are evaporative emissions and occur only for HC. Eight different vehicle types are considered. Emission factors are given in function of speed or, if such detailed information is not available, for three different road types. For gasoline vehicles <3.5 t, the study also takes into account the age of the vehicle and the legislation to which it conforms. Zierock et al. also give information on the fuel consumption per km. This allows us to compute the change in SO_2 and CO_2 emissions due to an additional vehicle-km, for which the Corinair working group gives no data. Information on the emissions of SO_2 and CO_2 in function of fuel consumption are presented in a study by Econotec (1990).

Having determined on the basis of the speed-flow relationship how fast the additional car is driving, this information is sufficient to compute the direct emissions associated with the additional car-km, if we know the vehicle characteristics. For some vehicle types we do not have information on the speed-emission relationship. In that case emissions per km are determined on the basis of the road type.

At this moment, the indirect effect on the emissions by the other vehicles can only be calculated for gasoline passenger cars. For the other vehicle types the relationship between speed and fuel consumption or emissions is not available.

Adding the direct and the indirect effect, we obtain the overall effect on emissions due to an additional vehicle-km. This overall effect is not necessarily larger than the direct effect, since the indirect effect of the additional car-km will not necessarily be to increase total traffic emissions. It is possible that a decrease in speed leads to a decrease in emissions. In that case the indirect effect will partially offset the direct effect. Both the direct and the indirect effect depend on the characteristics of the different vehicles concerned and on the speed at which or the type of road on which they are driving. Therefore it is clear that it will be impossible to speak of 'the' marginal social air pollution cost.

b. The monetary valuation of the change in emissions

After computing the change in emissions, it has to be given a monetary value. Ideally, this would involve the determination of the effect of the change in emissions on the concentration levels of the different primary and secondary air pollutants concerned. In order to obtain this information, one needs dispersion models which predict the spread of pollutants from their origin (the vehicle) and transformation models which describe how different pollutants can react together to form so-called secondary air pollutants. For some pollutants these models will be relatively simple, for others they will be extremely complex. But in either case it can generally be said that the scientific literature cannot provide us yet with the required models. In the imaginary case in which this problem would not exist, the next step would consist of establishing the effects of the concentrations measured in the air and the extent to which the pollution caused by the additional vehicle-km aggravates these effects. In the literature the effects of the different air pollutants - as they are known today - are discussed extensively. However, quantitative expressions which relate different kinds of air pollution to their effects are less generally available. The effect of an additional vehicle-km is even more difficult to establish. Finally, one has to put a monetary value on the effects of air pollution and more specifically on the marginal effect caused by the additional vehicle-km. Less problems arise at this stage. The economic literature on the monetary valuation of air pollution effects is relatively well developed. However, complete applications for Belgium or other countries are not yet available. Moreover there is no guarantee that the results for other countries can be carried over to Belgium. Finally, the different methods which have been applied yield varying results.

The difficulties encountered in the different stages make it clear that the procedure described cannot easily be put into practice. Therefore, instead of estimating the social marginal air pollution costs in a direct way, we will use alternative, indirect approaches to put a monetary value on the extra emissions caused by an additional vehicle-km. Two different approaches are proposed: one for the monetary valuation of NO_x, SO_2 and HC emissions and one for the valuation of CO_2 emissions. The difference in approach is mainly explained by a difference in the available data.

For NO_x, SO_2 and HC the monetary valuation approach which we propose to use is described in a detailed way in Mayeres (1992). In this paper we will limit ourselves to a general discussion of the method. The approach starts by putting forward emission reduction objectives for the different air pollutants, based on existing international agreements to which Belgium has adhered. It is then calculated at what costs the required emission reductions can be achieved in the initial situation, i.e. the situation before the change in vehicle-km takes place. In order to do so one needs information on the different emission abatement techniques, their abatement potential and their unit reduction costs. This information is used to construct marginal abatement cost curves after ranking the best available control technologies on the basis of their cost-effectiveness.

Applying the cost data to the initial emissions in 1989, it can be calculated how and at what cost the required emission abatement can be realized.

The next step consists of analyzing the consequences of the change in emissions due to the additional car-km. If the emissions of the transport sector are larger than in the initial situation, emissions have to decrease elsewhere in order to reach the internationally agreed objective in the new situation. The social cost of the emissions caused by the additional car-km is then set equal to the costs of achieving this emission reduction. If emissions have decreased with respect to the initial situation, there is no longer a social cost but a social benefit which is set equal to the cost savings which can be realized when trying to reach the total emission target in the new situation. The decrease in emissions entails that in order to realize the objective, less effort is needed to decrease emissions elsewhere.

The approach makes a number of important assumptions. First of all, it assumes that the emission reductions take place in a cost-effective way, i.e. the cheapest technologies are applied first. Therefore, as total emissions increase higher social marginal costs will be associated with additional emission units. Secondly, it is assumed that there are no indivisibilities in the emission abatement possibilities. Thirdly, the marginal social costs will depend heavily on the objective which is put forward. The less restrictive this objective, i.e. the more easily it can be reached, the lower will be the marginal social costs. Finally, the method assumes that the damage associated with the different air pollutants is the same no matter where and when they are emitted.

For CO_2 the energy-carbon tax of $10 per barrel of oil which has recently been proposed by the EC, is interpreted as the marginal willingness to pay of the EC for decreases in CO_2 emissions. A social cost of 10$ per barrel corresponds to approximately 725 BF per tonne CO_2 in 1989 prices. This figure can then be used to calculate the social costs of the extra CO_2 emissions caused by an additional vehicle-km.

c. Results

Applying the two methods described to quantify the marginal social air pollution costs of car use, yields the results which are summarized in Table 6. The findings refer to the sum of the direct and indirect effect on air pollution of the additional car-km. For their interpretation one needs to bear in mind the various assumptions which were put forward in the previous paragraphs. The values obtained for the total effect depend on the fuel type, the age and the cylinder capacity of the car which drives the additional km. In all cases the highest values are obtained when the additional km is driven by a gasoline car. The lowest costs are associated with diesel cars[5]. For almost all traffic conditions considered the marginal external air pollution costs are smaller than BF 1. For heavy congestion on urban roads and highways they are somewhat higher.

2. The marginal external noise costs associated with car use

a. The effect on noise of an additional car-km

In order to calculate the marginal external noise costs, it needs to be determined what is the effect on the noise level of an additional car-km. According to Lamure (1990), $L_{eq}(dB(A))$[6] can be expressed approximately as:

$$L_{eq}(dB(A)) = 20 \log s - 10 \log d + 10 \log q + \text{constant} \qquad (10)$$

where:

s : speed (km/h)
d : distance from the infrastructure (m)
q : traffic flow (PCU/h)

In this equation, it is assumed that in terms of their effect on noise, trucks and buses are equivalent to 10 cars (Lamure (1990)). From equation (10) it is clear that an additional PCU will affect Leq(dB(A)) both directly and indirectly (through its influence on s). For a given distance from the infrastructure this formula allows us to compute the marginal change in the noise level due to an additional PCU. The total effect on noise is not necessarily larger than the direct effect and can even become negative. In the cases where an increase in q decreases speed, the decrease in speed will partially or completely offset the direct effect of the increase in q. If it more than offsets the direct effect, the total effect becomes negative.

TABLE 6

The marginal air pollution costs of car use: monetary valuation

			URBAN		HIGHWAY				OTHER		
			Off peak	Peak	No congestion	Light congestion	Medium congestion	Heavy congestion	No congestion	Light congestion	Heavy congestion
Initial traffic flow			210	472.5	1375	3125	4500	5625	180	480	2040
New traffic flow			211	473.5	1376	3126	4501	5626	181	481	2041
Initial speed (km/h)			38.375	29.1875	115	110.5475	76.792	36.2245	74.5	72.745	57.535
New speed (km/h)			38.375	29.1525	115	110.54476	76.75594	36.18844	74.5	72.73525	57.52525
TOTAL MARGINAL EXTERNAL AIR POLLUTION COSTS (BF 1989/Car-km) IF THE ADDITIONAL KM IS DRIVEN BY A CAR OF TYPE											
Gasoline car											
	PRE-EEC	cc < 1.4	0.8086	1.0142	0.5675	0.5466	0.4461	1.4660	0.6033	0.6037	0.6607
		1.4 < cc < 2	0.8628	1.0697	0.7270	0.6967	0.5366	1.5201	0.6909	0.6891	0.7227
		cc > 2	0.9485	1.1567	0.8952	0.8586	0.6551	1.6056	0.8066	0.8026	0.8174
	70/220/EEC & 74/290/EEC	cc < 1.4	0.6954	0.8829	0.5086	0.4880	0.3707	1.3492	0.5244	0.5221	0.5508
		1.4 < cc < 2	0.7447	0.9346	0.6600	0.6315	0.4533	1.3986	0.6028	0.5973	0.6072
		cc > 2	0.8055	0.9935	0.9226	0.8793	0.6037	1.4585	0.7477	0.7378	0.6815
	77/102/EEC	cc < 1.4	0.6866	0.8703	0.7052	0.6598	0.4040	1.3391	0.5515	0.5445	0.5933
		1.4 < cc < 2	0.7260	0.9165	0.7658	0.7185	0.4460	1.3797	0.5922	0.5842	0.6235
		cc > 2	0.7789	0.9772	0.8368	0.7863	0.5018	1.4340	0.6479	0.6400	0.6820
	78/665/EEC	cc < 1.4	0.7400	0.9127	0.9033	0.8468	0.5181	1.3898	0.6614	0.6512	0.6741
		1.4 < cc < 2	0.7940	0.9733	0.9805	0.9221	0.5758	1.4450	0.7177	0.7064	0.7195
		cc > 2	0.8806	1.0672	1.0886	1.0268	0.6670	1.5328	0.8087	0.7974	0.8124
	83/351/EEC	cc < 1.4	0.6099	0.7817	0.5463	0.5092	0.3083	1.2603	0.4588	0.4543	0.5290
		1.4 < cc < 2	0.6617	0.8413	0.5813	0.5431	0.3418	1.3136	0.4928	0.4886	0.5684
		cc > 2	0.7458	0.9289	0.6470	0.6096	0.4003	1.3983	0.5500	0.5447	0.6124
Diesel car			0.2505	0.3489	0.3089	0.2884	0.1572	0.9775	0.2169	0.2130	0.2251
LPG car			0.5108	0.6092	0.5445	0.5239	0.3927	1.2130	0.4187	0.4148	0.4269
Average			0.5972	0.7557	0.6324	0.5933	0.3685	1.2491	0.4927	0.4864	0.5247

NOTE: The calculation of the marginal external air pollution costs uses the following monetary values per g emission:

Pollutant	Monetary value per g	Emission reduction objective which lies at the basis of the monetary value
NOx	0.089	Reduction of NOx emissions by 30% w.r.t. 1980 (objective adopted by Belgium additional to Sofia Protocol)
HC	0.1826	Reduction of HC emissions by 30% w.r.t. 1987 (Geneva Protocol)
SO2	0.013	Reduction of SO2 emissions by 30% w.r.t. 1980 (Helsinki Protocol)

b. The monetary valuation of the effect on noise of an additional car-km

There is no market for peace and quiet. Therefore, to calculate directly monetary damage functions for noise, it is necessary to make use of "surrogate markets" or "hypothetical markets". In this discussion we will focus on the results from the surrogate market approach which is based on the fact that some markets may reflect the

WTP of individuals for peace and quiet (Alexandre and Barde (1987)). The hedonic prices approach, which is a variant of the surrogate market approach, is the most widely used method for the evaluation of the social costs of noise. The basic idea underlying this technique is that the value of a house depends not only on its intrinsic characteristics, but is also a function of a number of environmental attributes, such as accessibility, proximity to schools, shops and parks and pollution. If the value of a house is amongst other factors a function of noise, this means that when individuals buy or rent a house, they have the possibility within their price range of buying a property in a quiet location rather than a similar property in a noisy location. It is reasonable to expect that - ceteris paribus - houses located in noisy areas are of less value than those located in quiet areas. Therefore the housing market constitutes a surrogate market for noise (Pearce and Markandya (1989)).

The hedonic prices approach is based on a number of underlying assumptions, which can be criticized. The first assumption is that of consumer's sovereignty. Individuals are supposed to have the possibility of buying more or less quiet on the housing market. But in reality, a lot of financial, social and cultural constraints prevent people from changing houses and location. Moreover, it is not known how far people are aware of the effects of noise. Therefore it is possible that their behaviour does not fully reflect the effects of noise. Furthermore, house price differentials can only be identified if noise is a localized phenomenon. If noise is widespread (e.g. in large conurbations) mobility may be constrained and no price differentials can be identified. Secondly, the method assumes that the hedonic price is the same for everyone. However, not only the perception of noise will differ between individuals but also their valuations. So what is measured is a mixture of different functions with a number of unknown biases. Because of this the exact meaning of the hedonic price is not known. Thirdly, it is assumed that the individual's valuation of noise is independent of his overall level of utility. This may not always be the case.

There are also a number of practical problems associated with hedonic pricing. In order to get good results, one must take into account all explanatory variables of housing prices. But the inclusion of too many explanatory variables will raise the difficult problem of multicollinearity. Secondly, the unit price of noise is taken as independent of the noise level, which is probably not supported in reality. The cost of noise is likely to be small or nil at low levels and increases as noise levels become higher. This also raises the question of a threshold below which no depreciation of house values takes place. Nelson (1982) and Pearce and Markandya (1989) summarize the results of North American hedonic price studies carried out on traffic noise. The majority of the findings correspond with a house value depreciation in the range of 0.4% to 0.5% per dB(A), giving a mean of 0.4%. The results refer to a standardized value house. This way one tries to eliminate the possibility that higher priced properties may have a greater depreciation than lower priced ones. Traffic noise is expressed in Leq units. According to Alexandre and Barde (1987) as a rule of thumb, a 0.5% house value depreciation per dB(A) constitutes a reasonable guide and is based upon a substantial number of studies.

However, they point to the fact that it is probable that this depreciation rate is valid only above a certain noise threshold, say 50 dB(A) Leq, since most surveys show a very low level of annoyance below this level. Furthermore they mention the possibility that the unit percentage of depreciation increases both with the noise level and with the value of the house.

In this paper, a standardized value of BF 3,000,000 is assumed for a house. It should be noted that the 0.5% house value depreciation is valid only for a change in dB(A) during the rest of the lifetime of the house. However, the effect of an additional car-km is only temporary. This has to be taken into account when calculating the marginal external noise costs. Using an expected lifetime of a house of 50 years and a discount factor of 5%, we obtain a monetary value of BF 0.0996122 per dB(A) produced by an additional car-km. The results obtained in this way are summarized in Table 7. The absolute value of the marginal external noise costs is small in all cases. The results confirm the remark that it is possible that the indirect effect more than offsets the direct effect. In those cases, the overall effect is negative.

C. *Marginal accident costs*

1. Introduction

In the theoretical model it was shown that there may be three different categories of marginal accident externalities associated with

TABLE 7

The marginal external noise costs of car use: monetary valuation

	URBAN		HIGHWAY				OTHER		
	Off peak	Peak	No congestion	Light congestion	Medium congestion	Heavy congestion	No congestion	Light congestion	Heavy congestion
Initial traffic flow	210	472.5	1375	3125	4500	5625	180	480	2040
New traffic flow	211	473.5	1376	3126	4501	5626	181	481	2041
Initial speed (km/h)	38.375	29.1875	115	110.5475	76.792	36.2245	74.5	72.745	57.535
New speed (km/h)	38.34	29.153	115	110.54476	76.75594	36.18844	74.5	72.73525	57.52525
Distance from infrastructure (m)	7.5	7.5	20	20	20	20	8	8	8
Change in noise level (Leq dB(A))	0.007024	-0.00377	0.001215	0.000319	-0.00371	-0.00835	0.010328	0.002712	-0.00056
Number of houses exposed	200	200	50	50	50	50	100	100	100
MARGINAL EXTERNAL NOISE POLLUTION COSTS (BF 1989/Car-km)	0.139941	-0.07513	0.00605	0.00159	-0.01847	-0.04161	0.10288	0.027011	-0.00558

an additional car-km. Each will be discussed separately in this section.

a. The marginal accident costs associated with the risk of death or injury to the occupants of the additional passenger car

If an additional car-km is driven, the driver and the passengers of the car face the risk that they themselves may be killed or seriously injured. A proportion of these marginal costs is covered by the insurance premium and thus is private. But part of it is also imposed on others. Indeed, society will bear the police and ambulance costs and looses part or the total of the person's net contribution to current and future output[7]. Formally, one obtains:

$$E_f^d + E_s^d = p_f^d [X_f - C] + p_s^d [X_s - C^*]$$

where:

E_i^d: the externality associated with the risk of the driver or a passenger of the additional car being killed (i=f) or seriously injured (i=s) in an accident
p_i^d: probability that an occupant of a passenger car is killed (i=f) or seriously injured (i=s) in an accident
X_i: estimate of output loss, police and medical costs associated with a road fatality (i=f) or a serious injury (i=s)
C: discounted present value of the dead person's future consumption
C*: discounted present value of the reduction in future consumption by the seriously injured person

For our empirical analysis the probabilities p_i^d are derived on the basis of NIS (1989) and on the basis of an estimate of total distance travelled by passenger cars given by Cuypers (1992). p_f^d and p_s^d are found to be 1.69×10^{-8} and 1.51×10^{-7} respectively. The value of (X_f-C) is assumed to be BF 5,490,000. The average value of X_s is taken to be BF 2,190,000 (Jones-Lee (1990)). C* is assumed to be zero.

b. Marginal accident costs associated with the increased risk of death, injury or material damage to the other motorized road users

This category of marginal accident costs will only exist if an additional car-km changes the probability that other motorized road users are involved in different types of accidents. As was shown in the theoretical model, the additional car-km may influence these probabilities in several ways: directly and through its effect on speed and traffic composition. Whether the probabilities really change and - if they do - by how much, is an issue which can only be solved by identifying the relationship between accident rates and traffic flow. In the literature various assumptions are made concerning this relationship. In this paper we consider two different views which have been put forward.

Newbery (1988) uses a marginal to average accident rate ratio of 1.25. This entails that a quarter of the costs of mutually caused accidents is external. In that case, even if insurance completely compensates the accident victims, there is still an externality equal to a quarter of the average costs of mutually caused accidents. Formally, the marginal accident externality associated with the increased risk of death, serious injury or material damage to other motorized road users (E^t) can then be expressed as:

$$E^t = 0.25 \; (p_f^t W_f + p_s^t W_s + p_m^t W_m)$$

where:

p_i^t: risk of a fatality (i=f), serious injury (i=s) or material damage (i=m) in a mutually caused accident
W_f: the value of a statistical life
W_s: the value of avoidance of a statistical serious injury
W_m: average material damage

On the basis of NIS (1989) the accident risks can be computed. The risk of a fatality p_f^t is found to be 8.6 x 10^{-9}, the risk of a serious injury p_s^t is 1.1 x 10^{-7} and the risk of material damage p_m^t is 4.4 x 10^{-7}. W_m is calculated on the basis of Dubus (1986). The derivation of W_f and W_s will be discussed in section III.C.2.

A different assumption is made by Jones-Lee (1990). He assumes that the number of accidents per car-km and traffic flow are independent. This view is supported by the findings of Vitaliano and Held (1991). Their analysis of empirical evidence for urban and rural roads in New York State (USA) shows that the volume of road accidents is proportional to the volume of traffic. A similar position is taken by the UK Department of Transport (1987) in its COBA 9

- manual and by the US Federal Highway Administration (1982). A possible explanation for a marginal to average accident rate ratio of 1 could be "risk-compensation": road users choose a certain level of perceived risk with which they are comfortable. A deterioration of travel conditions, due to e.g. heavier traffic, induces more caution and does not increase the probability of an accident.

Under the assumption of a marginal to average accident rate ratio of 1, there exists no marginal accident externality associated with the increased risk to other motorized road users.

c. Marginal accident costs associated with the increased risk of death or injury to pedestrians and cyclists

When a driver takes a vehicle on the road, he imposes the risk that he may kill or injure a pedestrian or a cyclist. This marginal accident cost should be included in external costs if insurance does not or does not completely cover the costs of these accidents to pedestrians or cyclists. Define E_f^o and E_s^o as the externalities with the risks of death and serious injury imposed by car drivers on other road users. The sum of these two externalities can be expressed as

$$E_f^o + E_s^o = p_f W_f + p_s W_s$$

where :

p_f: probability that the car driver kills a pedestrian or a cyclist in an accident

p_s: probability that the car driver seriously injures a pedestrian or a cyclist in an accident

For traffic on highways, p_f and p_s are assumed to be zero. For urban and other roads the calculation of p_f and p_s is based on NIS (1989). They are found to be 6.65×10^{-9} and 5.12×10^{-8} respectively.

For all the categories of marginal external accident costs, a central input is the value of a statistical life and the value of avoidance of a statistical serious injury.

2. The value of transport safety

One can distinguish different approaches for the definition and estimation of values of safety. The most interesting one is the willingness-to-pay (WTP) approach, which is based upon the economic literature (Drèze (1962), Schelling (1968), Mishan (1971), Jones-Lee (1976), Bergstrom (1982)). It lies within the tradition of welfarist consequentialism and is based upon the ex-ante assessment of uncertain consequences. The approach does not deal with certain deaths but uses the concept of statistical death or injury. It attempts to determine the amounts that those who are affected, would individually be willing to pay for typically small improvements in their own and others' safety. These amounts are then aggregated across all individuals to arrive at an overall value for the safety improvement concerned. Jones-Lee (1976) has shown that if (a) the safety improvement entails a reduction in the expected number of fatalities of precisely one, (b) individual probability reductions are small, (c) the affected group is not significantly atypical in terms of income, age, attitudes to risk etc., then the value of statistical life for such a safety improvement will be independent of the precise size of the affected group and the precise pattern of individual risk reductions.

Safety improvements also have direct economic effects. To the extent that people do not take this into account in assessing their WTP for improved safety, values of statistical life and safety should be increased by an allowance for these factors.

The application of the WTP approach requires empirical estimates of the MRS of wealth for risk of death or injury. These can be obtained in two ways: from revealed preference (RP) or from stated preference (SP) information[8]. The RP approach tries to identify and observe choices in situations in which people actually trade off wealth or income for physical risk.

The advantage is that it deals with actual choices. However the method also has a number of disadvantages. First of all, pure wealth/risk trade-offs are rare. One usually has to disentangle the effects of other factors. Secondly, for situations in which wealth/risk trade-offs are readily identifiable, somewhat biased samples of individuals can be expected. The main variant of the approach is formed by the hedonic wage risk studies which analyze wage differentials for hazardous occupations[9]. They are an application of the hedonic approach to the valuation of benefits. The wage rate paid for a job reflects forces of supply and demand on the labour market. However, what is supplied and demanded is determined by the job characteristics or attributes. One of these attributes is safety, so if the market functions freely one would expect, ceteris paribus, that employees want higher wages to compensate for higher risk and employers want to see lower wages to compensate for expenditure on higher safety. This leads to a bargaining process resulting in a price for safety. This price is called the hedonic wage. The approach is based on the assumption that (a) the labour market operates freely and is in equilibrium and that (b) workers actually perceive workplace safety risks correctly. If the first assumption is violated, the estimated valuation can be biased. The violation of the second assumption presents a large number of problems. If the workplace safety risks are misperceived in a random way, the standard errors of the estimated wage-risk premium will increase. But only if there is some systematic pattern in the misperceptions, the estimate will be biased. If employees are not aware of the risks, a wage premium might not exist and one might wrongly conclude that the price of the risk is zero. If there is awareness of the risk, the problem arises of whether true and perceived risk coincide. Due to data limitations an additional problem may arise (Pearce and Markandya (1989)). Very often the risk variable used in hedonic wage risk studies only includes the risk of fatal accidents and a comparable variable for nonfatal accidents and illnesses is not included. In those cases the coefficients obtained for the risk of fatal accidents may pick up some of the compensating differential for nonfatal accidents and illnesses (Marin and Psacharopoulos (1982)).

The SP approach[10] consists of asking a sample of people more or less directly about their willingness to pay for improved safety or required compensation for increased risk. Its advantage is that the researcher can tailor his survey instrument and sampling procedure to provide precisely the kind of information he requires. However it suffers from the disadvantage that it deals with hypothetical rather than actual choices.

In this paper we will use a value of statistical life of BF 42,000,000 proposed by Jones-Lee (1990). This value was obtained using estimates based on median[11] responses to different SP studies. Moreover, Jones-Lee et al. (1985) observed in their SP study that a "substantial majority of respondents appear not to have taken account of the 'direct' economic effects of a safety improvement". Therefore the value of statistical life should be increased by police and medical costs as well as by net output losses. This amounts to a total value of statistical life of BF 47,490,000.

The studies reviewed up to now do not say anything of the value of avoidance of a statistical serious injury. This value was derived by means of a stated preference study by O'Reilly et al. (1992). They find a ratio of the marginal rate of substitution of wealth for risk of serious injury to the marginal rate of substitution of wealth for risk of death of the value of 0.117. This ratio must be multiplied by the value of statistical death (excl. of police and medical costs and excl. of net output losses) to obtain the value of avoidance of statistical serious injury. To this figure should be added the net output losses, police and medical costs associated with a serious injury.

3. Results

Table 8 summarizes the results of the calculation of the marginal external accident costs of car use. Separate values are presented for urban and other roads on the one hand and highways on the other hand. Due to a lack of data the values could not be differentiated according to level of congestion. Case 1 presents the results under the assumption that the marginal to average accident rate ratio equals 1. Marginal accident externalities are then BF 1.1 in the case of urban and 'other' roads and BF 0.4 on highways. In case 2 a marginal to average accident rate ratio of 1.25 is assumed, which increases the values to resp. BF 1.5 and BF 0.8[12].

D. *The total marginal external costs of car use*

Adding the marginal external congestion cost (MECC), marginal environmental cost (MEEC) and marginal accident externalities (MEAC), one obtains the total short-run marginal external cost of an additional car-km. For the nine cases considered in the empirical exercise, FIGURE 1 presents the total marginal externality if the additional car-km is driven by an average car of 1989 and under the assumption that the marginal to average accident rate ratio equals 1. Table 9 gives more information on the contribution of the different cost categories. In the interpretation of Figure 1 and Table 10 the assumptions made to derive the results have to be borne in mind. The results show that it is impossible to speak of 'the' marginal external cost of car use. The marginal external cost will vary according to road type, level of congestion, traffic composition and a number of other factors which were pointed out in the previous sections. The marginal external costs range between BF 1.1 for uncongested

TABLE 8

The marginal external accident costs of car use

	MARGINAL EXTERNAL ACCIDENT COSTS (BF 1989/Car-km)	
	HIGHWAY	URBAN & OTHER ROADS
CASE 1: marginal to average accident rate ratio = 1		
$E_f^d + E_s^d$	0.4233	0.4233
$E_f^o + E_s^o$	0	0.6799
Total	0.4233	1.1032
CASE 2: marginal to average accident ratio = 1.25		
$E_f^d + E_s^d$	0.4233	0.4233
E^t	0.3611	0.3611
$E_f^o + E_s^o$	0	0.6799
Total	0.7844	1.4643

highways and BF 77 for heavily congested highways. In uncongested or lightly congested conditions on highways, the main contribution is formed by MEEC. On 'other' roads MEAC are the main contributors in these traffic conditions. In the case of medium and heavy congestion MEEC and MEAC become less important for both road types and the main contribution is made by MECC. For heavily congested traffic on highways the contribution of MECC increases up to 98%. On urban roads MECC already make a considerable contribution to total marginal external costs during the off-peak period. But also in this case they become more important as congestion levels increase. The contribution of MEEC cannot generally be said to be unimportant. For uncongested traffic they are responsible for a considerable part of marginal external costs. However, as the level of congestion increases, their relative importance diminishes.

TABLE 9

The contribution of the different cost categories to total short-run marginal external congestion costs

	(1) CITY OFF-PEAK	(2) CITY PEAK	(3) HIGHWAY NO CONGESTION	(4) HIGHWAY LIGHT CONGESTION	(5) HIGHWAY MEDIUM CONGESTION	(6) HIGHWAY HEAVY CONGESTION	(7) OTHER NO CONGESTION	(8) OTHER LIGHT CONGESTION	(9) OTHER HEAVY CONGESTION
MEAC	1.1032	1.1032	0.4233	0.4233	0.4233	0.4233	1.1032	1.1032	1.1032
MEEC	0.737	0.681	0.638	0.595	0.350	1.207	0.596	0.513	0.519
Air	0.597	0.756	0.632	0.593	0.369	1.249	0.493	0.486	0.525
Noise	0.140	-0.075	0.006	0.002	-0.018	-0.042	0.103	0.027	-0.006
MECC	2.510	12.767	0.000	0.313	13.348	75.643	0.000	0.566	4.405
Time	2.438	12.511	0.000	0.343	13.489	74.193	0.000	0.569	4.385
Operating	0.072	0.257	0.000	-0.030	-0.140	1.450	0.000	-0.003	0.020
TOTAL (BF/Car-km)	4.350	14.551	1.062	1.331	14.122	77.273	1.699	2.183	6.027

CONTRIBUTION

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
MEAC	25.36%	7.58%	39.87%	31.80%	3.00%	0.55%	64.94%	50.55%	18.30%
MEEC	16.94%	4.68%	60.13%	44.69%	2.48%	1.56%	35.06%	23.52%	8.61%
MECC	57.70%	87.74%	0.00%	23.51%	94.52%	97.89%	0.00%	25.93%	73.08%

Note:
MEAC: marginal external accident costs - MEEC: marginal external environmental costs - MECC: marginal external congestion costs

IV. CONCLUSION

Based on the presently available statistical data, the empirical exercise presented in this paper, has attempted to derive a monetary value for the marginal external costs of car use in Belgium. The results can be considered as a first approximation of the external costs to society associated with an additional car kilometre. In order to obtain more accurate estimates, an improvement of the statistical information on car use in Belgium is necessary.

If one wants to use the results for the determination of the price which should be paid by car users, a number of remarks need to be taken into account. As was pointed out repeatedly in the analysis, the results are valid only for the specific traffic conditions considered. The marginal external costs are a function of different variables which were discussed in the previous sections. One of these variables is traffic volume. When determining the correct charge to car users one should therefore look at the equilibrium marginal external costs, i.e. those costs which correspond with equilibrium traffic. Secondly, it must be noted that the marginal external costs should be added to the marginal private user costs exclusive of taxation or excises. Or, alternatively, they should be compared with the taxes and excises per kilometre which are paid by car users. Finally, it is important to mention that the existence of marginal external costs should not necessarily or solely lead to additional taxation of car use. Other instruments could also be considered. For instance, in the case of air pollution the government could decide to impose a certain technology rather than using taxation as an instrument. This would reduce the marginal external environmental costs and thus would alter the price charged to the car user.

NOTES

1. The research reported in this paper has been conducted under contract TR/C8/019 (promotor S.Proost) of the National Impulse Programme Transport and Mobility initiated by the Belgian State - Prime Minister's Service - Science Policy Office. The scientific responsability is assumed by its author.
2. based on NIS (1990)
3. In the long-run people will adjust their behaviour, which will modify the magnitude of the congestion cost. As is put forward by Newbery (1987) the relationship between the long-run and the short-run marginal congestion costs is given by:

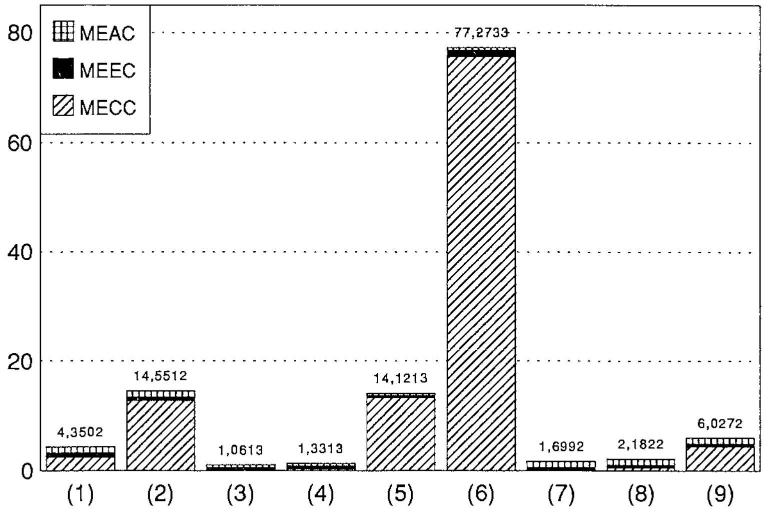
$$LRMC = SRMCC \,/\, [1 + (\varepsilon.SRMCC)/c]$$

where ε is the elasticity of demand for trips and c is the private cost of travel.

4. For a discussion of the sources and effects of air and noise pollution by passenger cars, I refer to Buna (1987), Lassière (1976), Linster (1990), Nelson (1987) and OECD (1986).
5. The inclusion in the analysis of the emissions of particulate matter would increase the marginal external costs associated with diesel cars.

FIGURE 1

The total short-run marginal external costs of an additional car-km (BF 1989 per car-km)



MEAC : Marginal external accident costs
MEEC : Marginal external environmental costs
MECC : Marginal external congestion costs

6. L_{eq}, the energy mean sound level, is a noise index used by various countries. It gives the average sound level over a given period e.g. a full day (Lassière (1976)).
7. According to Jones-Lee (1990) this figure should be augmented by an allowance for the pain, grief and suffering experienced by the relatives and friends of the car occupants. Findings by Needleman (1976) and Jones-Lee et al. (1985) suggest that this allowance should consist of 50% of willingness-to-pay (WTP) for own safety. However, one might argue against this procedure that road users, when deciding to make a trip, already take into account the psychological effects on relatives and friends of a possible accident, exactly because they are relatives and friends. This argument was put forward by Newbery (1987) and an anonymous referee.
8. An overview of different RP and SP studies is given by Jones-Lee (1987) and Jones-Lee (1990).
9. See e.g. Thaler and Rosen (1973), Viscusi (1978), Brown (1980), Marin and Psacharopoulos (1982).
10. Important studies in the field of transport safety are Jones-Lee et al. (1985), Persson (1989) and Maier et al. (1989).
11. Arguments in favour of using median rather than mean valuations are presented in Jones-Lee (1990).
12. If, in addition, it is assumed that the additional car user does not take into account the psychological effects of an accident on his relatives and friends, the total values obtained must be increased by BF 0.7.

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